Mighty Ducts: Final Report

MAE 4344: HVAC Senior Design Projects

A system for the characteristics of fans and duct work fittings

Duct 2

HVAC Senior Design

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1 Introduction

In the past, there has been a lack of practical, hands-on undergraduate education in mechanical engineering at Oklahoma State University. This project will improve the education of future students by allowing them to gain hands on experience with HVAC systems. By creating a lab that is interactive, students will be able to have a greater understanding of HVAC systems by expanding their learning opportunities past simply theoretical discussion.

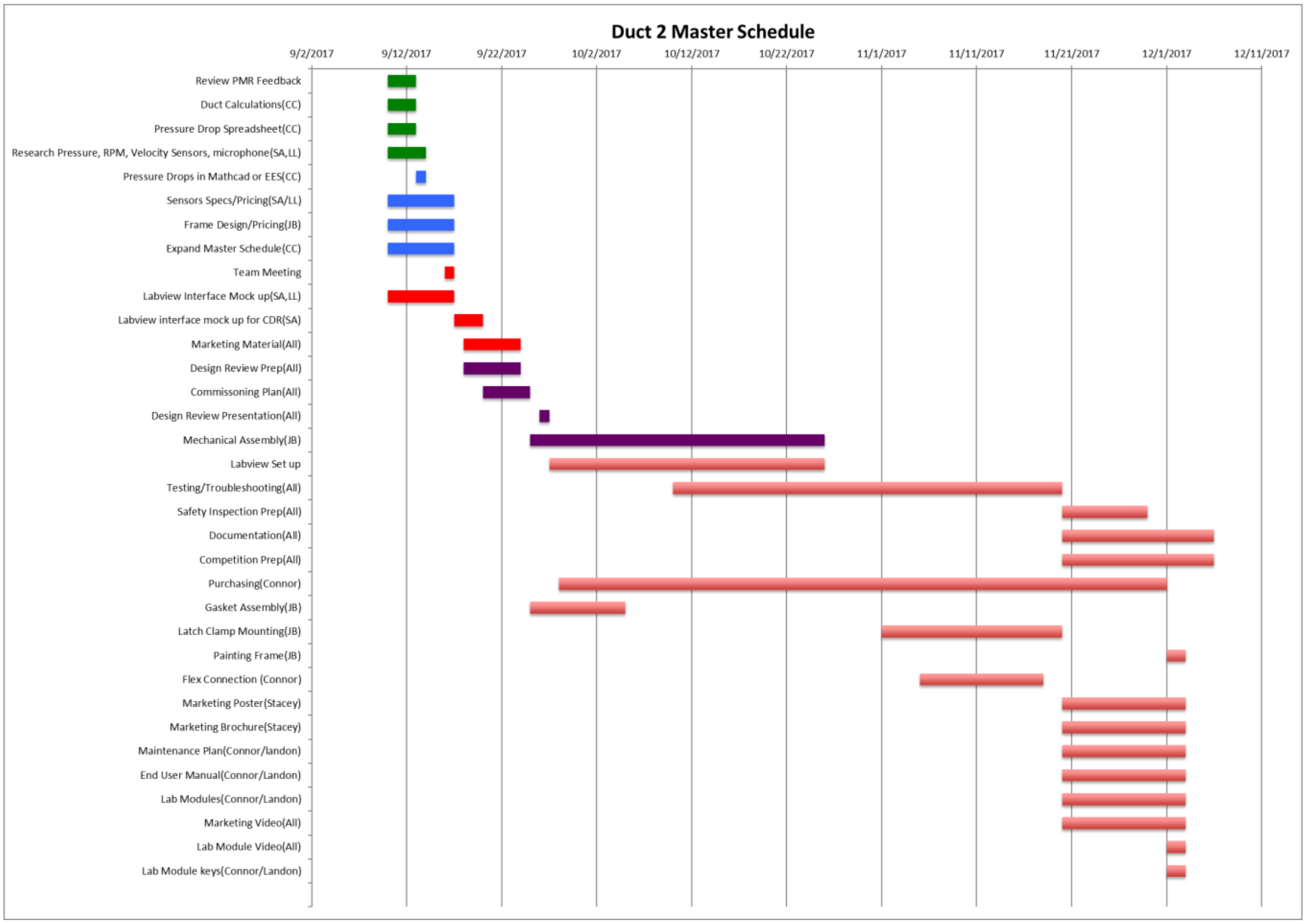
The Duct 2 goal is to create a cost efficient and user friendly system that focuses on ductwork and fan performance. Listed below are the experimental outcomes required by the supplied work statement.

- Production of experimental fan curve at various fan speeds achieved by manipulating system static pressure via flow modulating damper
- Experimental pressure losses experienced over various fittings at five different fan speeds.
- Determine the consequences of the series effect on duct fittings

The data acquisition system will be integrated with LabVIEW in order to record and analyze data after experimentation. Further detail on the sensor capabilities will be detailed in the Design Overview and Data Acquisition (DAQ) sections.

2 Project Planning

The project master schedule is shown below:



Duct 2 Master Schedule

Scheduling was a major priority after the Preliminary Management Review to ensure the project was brought back on track. Dependencies were a significant cause of concern early on in the design process. These concerns were overcome by making design assumptions that allowed the design process to continue while constantly communicating with other team members to ensure that solutions were still valid. Examples of this occurred during the design of the duct and frame while final sensors were still being selected. The size of the duct depended on the sensitivity of the sensors, while the framework needed to be designed around the size of the duct. The duct calculations program, executed in Mathcad, was designed to allow changes after sensor specifications were decided and pricing for the non-dependent aspects of the frame continued unhindered. The frame was also priced by the foot for unistrut and then updated for the final design after the other aspects of the duct size was selected.

3 Budget

The total cash budget for the project is $4000. Total costs divisions are shown below.

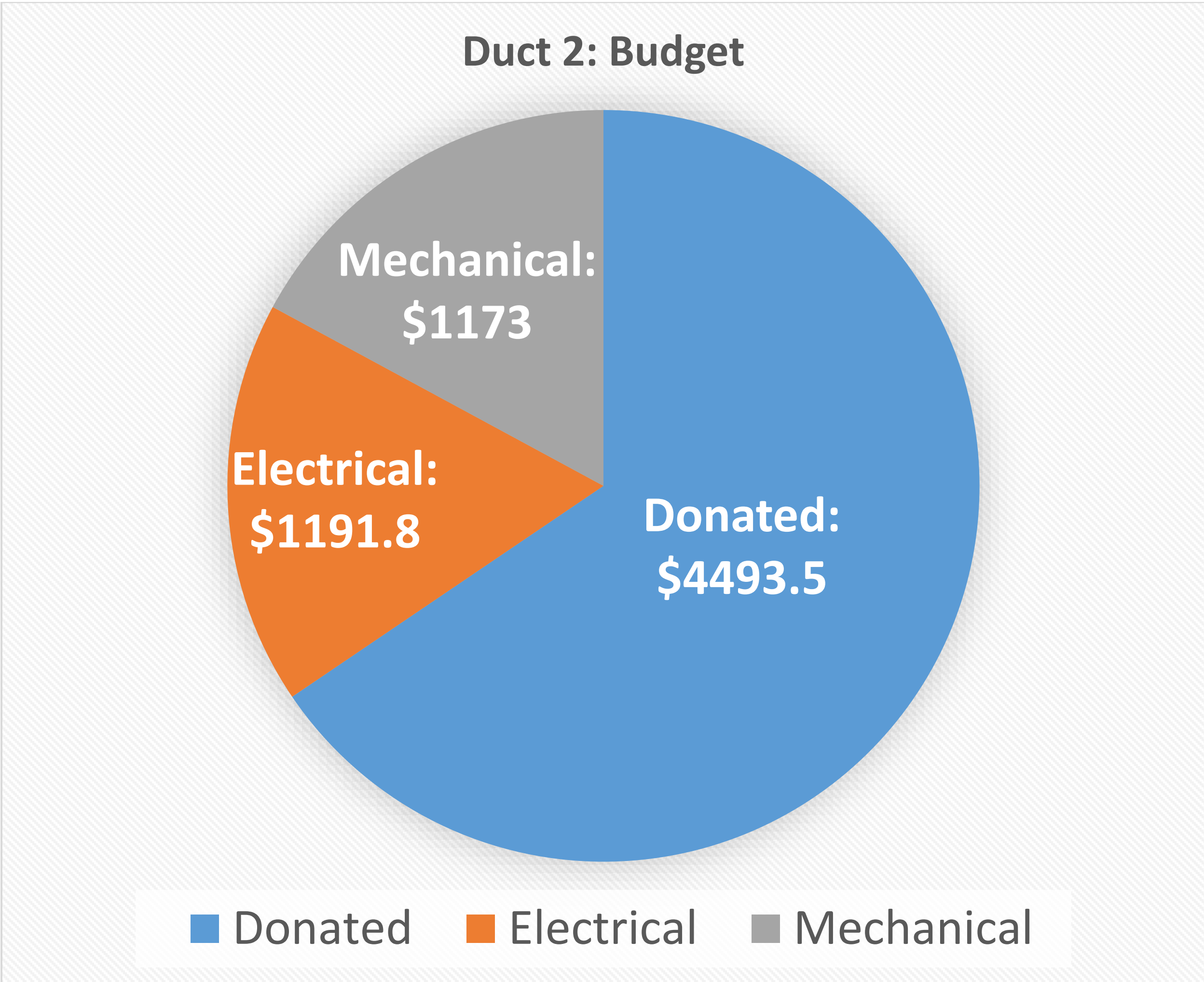


Figure 1

The cash costs are highest with the Electrical/DAQ portion of the system with the Mechanical portion being the next highest. The ductwork, fan, and pressure transducers were donated which allowed the project to be possible with the allotted cash budget.

Duct 2 was able to stay approximately $1300 under budget thanks to donated components and a driving principal of staying under budget as a design goal.

A detailed budget is shown in Appendix 1.

4 Design Overview

The system major design requirements are specified below:

- Ability to quickly change and test three fittings at five different fan speeds
- Manipulation of system static pressure via damper to record fan curves
- Measurement of the following quantities:
- Static pressure drop across fittings
- Fan volumetric flowrate
- Fan speed (RPM)
- System temperature
- Noise 1 m from fan inlet and system outlet
- Durable and transportable across facilities
- $4000 budget
- No specialized training required for operation
- Modifiable to allow flexibility in future use

These requirements were the main criteria for our selection of dimensions, sensors, and other equipment in our design.

5 Mechanical Design

Frame:

Figure 2: Fully Assembled Product: Image courtesy of James Vaught

The main support structure of the system will be constructed using a strut channel frame to house the ductwork and provide space for the user interface and work station. Strut channel is a user friendly material that was selected due to its ease of modification and rapid construction. The design allows for onsite assembly without the need for power tools should there be a need for long distance transportation that requires the system to be broken down. Otherwise, the structure is durable enough for smaller trips like those between classrooms and storage locations. The modularity of the design also allows for future adaptations and additions to the lab.

The unit was sized with a primary focus on design constraints and with a secondary focus on ease of use and quality of lab experiment. With the dimensions of 32 x 84 x 70 inches, the unit is well within the size constrains of the senior design work statement, and it is long enough to allow for a sufficient length of straight duct between the fittings and the exit for fully developed air flow at the designed duct size. This is beneficial because it provides optimum conditions for the data acquisition instruments. In addition, the supports for the duct work are at a height that allows for a comfortable level of viewing in the areas of most interest, the elbows and straight section coming off of the elbows.

This design is both mobile and compact. The open sided “shelf” design allows ease of access for the lab operator and increased visualization for the lab participants. At an estimated weight of 500 lb. the unit is easily transported on its 5” rubber casters by two able bodied participants.

5.1 Duct:

The ductwork section of the system will be constructed with 10 inch square duct. Justification for duct sizing was based on not exceeding fan power specifications and ensuring that measurable pressure drops would occur for the lowest flow case. The rectangular duct will easily allow for surface mounted sensors for the DAQ. The duct will also be constructed with the outward facing side made of Lexan. This, in conjunction with glow in the dark enabled string will allow for excellent flow visualization to view turbulence.

Working in conjunction with the DAQ division of our team, the smaller duct size (in comparison to the fan outlet) also benefited the instrumentation, since a smaller hydraulic diameter allowed the flow to become fully developed in a shorter distance (Bergman, et al). This fully developed flow will allow for more reliable measurements.

5.2 Pressure Taps:

The system uses Dwyer A-308 pressure taps. The taps are installed in 3/8 inch holes and then connect to ¼ inch ID tubing via a barbed fitting on the outside of duct. The taps exclusively measure static pressure and are recommended for use under 2500 FPM duct velocity. For the purposes of this project, average velocity should not exceed this threshold. If air velocity exceeded this limit, then accuracy would be reduced due to turbulence. The work statement uncertainty requirement of .04 inches of water column allows for some deviation due to turbulence. The pressure taps are shown below:

Figure 3: Dwyer 308 Static Pressure Taps: Source: https://www.grainger.com/category/pressure-and-vacuum-measuring/test-instruments/ecatalog/N-bcz?okey=dwyer+static+pressure&mkey=dwyer+static+pressure&refineSearchString=dwyer+static+pressure&NLSCM=17&EndecaKeywor

5.3 Damper

The production of fan curves requires a volume control damper. The requirements for the damper imply that the open area changes as it opens and closes so that system pressure, and therefore volumetric flow, change allowing the measurement of the fan curve. The procedure for producing the fan curve will be to set the fan motor to a certain RPM, and then measure the static pressure and flowrate. Next, the damper will be incrementally closed while recording the change in flow and static pressure for each setting. This will yield the fan curve for the system at the selected RPM. The opposing blade manual damper was supplied by Harrison-Orr and functions similar to the damper shown below:

Figure 3: Damper: mage source: https://blackhawksupply.com/products/8x12-vcd?gclid=EAIaIQobChMI7euhibvD1gIV3rbACh1Q2Aj7EAkYAyABEgJdUPD_BwE

This damper will also work to straighten flow from the fan outlet to assist in the validity of our velocity and pressure measurements by helping the velocity profile develop.

5.4 Fittings

Three fitting types were selected to be used in the system. Two fittings at a time will be used to reduce space requirements by doubling back towards the fan. The following fittings were selected from the limited number available from the ASHRAE Handbook (2009) since the ASHRAE fittings database was not available during this phase of the project.

RECTANGULAR FITTINGS

CR3-1 Elbow, Smooth Radius, Without Vanes

	C_p Values										
	H/W										
r/W	**0.25**	**0.50**	**0.75**	**1.0**	**1.50**	**2.0**	**3.0**	**4.0**	**5.0**	**6.0**	**8.0**
0.50	1.53	1.38	1.29	1.18	1.06	1.00	1.00	1.06	1.12	1.16	1.18
0.75	0.57	0.52	0.48	0.44	0.40	0.39	0.39	0.40	0.42	0.43	0.44
1.00	0.27	0.25	0.23	0.21	0.19	0.18	0.18	0.19	0.20	0.21	0.21
1.50	0.22	0.20	0.19	0.17	0.15	0.14	0.14	0.15	0.16	0.17	0.17
2.00	0.20	0.18	0.16	0.15	0.14	0.13	0.13	0.14	0.14	0.15	0.15
	Angle Factor *K*										
θ	**0**	**20**	**30**	**45**	**60**	**75**	**90**	**110**	**130**	**150**	**180**
K	0.0	0.31	0.45	0.60	0.78	0.90	1.00	1.13	1.20	1.28	1.40

$C_o = KC_p$ where K = angle factor

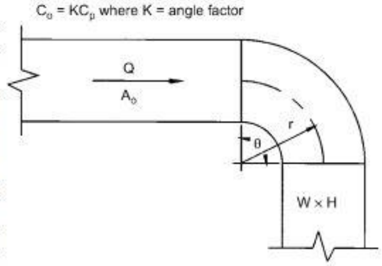


Figure 4: CR3-1

CR3-9 Elbow, Mitered, 90 Degree, Single-Thickness Vanes (1.5 in. Vane Spacing)

$C_o = 0.11$

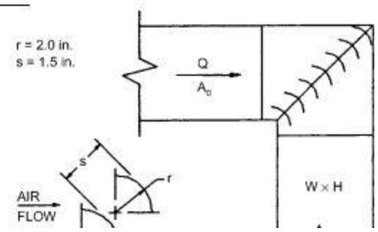


Figure 5: CR3-9

CR3-6 Elbow, Mitered

	C_o Values										
	H/W										
θ	**0.25**	**0.50**	**0.75**	**1.00**	**1.50**	**2.0**	**3.0**	**4.0**	**5.0**	**6.0**	**8.0**
20	0.08	0.08	0.08	0.07	0.07	0.07	0.06	0.06	0.05	0.05	0.05
30	0.18	0.17	0.17	0.16	0.15	0.15	0.13	0.13	0.12	0.12	0.11
45	0.38	0.37	0.36	0.34	0.33	0.31	0.28	0.27	0.26	0.25	0.24
60	0.60	0.59	0.57	0.55	0.52	0.49	0.46	0.43	0.41	0.39	0.38
75	0.89	0.87	0.84	0.81	0.77	0.73	0.67	0.63	0.61	0.58	0.57
90	1.30	1.27	1.23	1.18	1.13	1.07	0.98	0.92	0.89	0.85	0.83

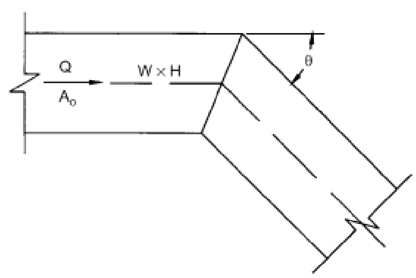


Figure 6: CR3-12

The fittings were chosen to shown how vane placement and size can affect airflow and show a comparison of rounded elbows as a more easily constructed option in comparison to vaned double 90 degree elbows. The CR3-1 elbow will be constructed with H/W=1 and an Angle Factor of 1 for a Cd=.21. The CR3-6 Elbow will have H/W=1 and theta=90 degrees for a Cd=1.18

5.5 Fitting Attachment

The duct fittings will be connected via latch clamps. A total of 4 clamps per connection will be used to secure the duct fittings and ensure minimal leakage. Each latch was attached on the top and bottom face of the duct on the outside edges.

Our system will use latch clamps similar to the one show below:

Figure 7: Latch Clamp: Image source: http://www.homedepot.com/p/POWERTEC-700-lb-431-Latch-Action-Toggle-Clamp-20307/207181689

These clamps will allow the user to quickly and securely attach the fittings for testing. The clamp shown above can provide around 220 pounds of force to seal the gaskets between each joint.

5.6 Flow Visualization

Figure 8: Flow Visualization Image courtest of Stacey Allen

Figure 9: Flow Visualization Pt 2: Photo courtesy of Stacey Allen

The flow visualization for this system was accomplished by placing small tufts of string into the duct. The string was No. 60 weight string. This was chosen based off of similar systems and aerospace test that used tufts of string as their flow visualization. This weight of the string allowed us to achieve a light enough string that it did not disrupt the flow but heavy enough that it still showed the air flow well. Each tuft was three inches long and consisted of 6 strands of string. These tufts are tied longer strings two inches apart and the long strings were placed at one foot intervals along each section of straight duct and along each of the fittings. We deiced to use fluorescent string coupled with a black background so that the string would be easy to see. A black light flashlight was also purchased for if the system is used in a room where all the lights can be turned off. By shining the black light on the string in a dark room, the flow visualization gives a very interesting effect that is sure to impress and excite undergraduate students.

6 Data Acquistion

6.1 UMIK-1 Microphone

Figure 10: miniDSP (2017)

Brand: miniDSP

Sensor: Umik-1

Specs:

- 0– 133 dB Noise Range
- 24-bit Resolution
- 20Hz – 20 KHz Frequency Range
- USB powered

We chose this microphone because it is affordable, handheld, and meets all required specifications and uncertainties. This meter will allow students to gather accurate sound level readings as well as be hands on and place the sensor in optimal spots along the setup. Students will need to measure sound level in order to understand the importance of comfort among machine design as well as ensuring safety requirements are fulfilled. This microphone also comes with an automatic calibration file.

6.2 ROS –W Remote Optical LED Sensor

Figure 11: Monarch Instruments (2017)

Brand: Monarch Instruments

Sensor: ROS-W

Specs:

- 1 – 250,000 RPM Range
- 3 ft. operating distance
- TTL pulse proportional to input
- Reflective tape included

We chose to use the ROS-W LED sensor to measure fan speed because it is able to measure rpm at the correct distance, provide a digital output, and meets the required specifications. The sensor will be easily mounted as all necessary mounting components are provided along with an 8 ft. output cable. This sensor uses reflective tape to count the number of times the LED pings the tape. The sensor has a digital output which saves analog space and can easily be converted to RPMs using LabVIEW.

6.3 Pressure Transducers

Figure 12: WorkACI (2017)

Brand: Automation Components, INC (ACI)

Sensor: DLP Series

Specs:

- 0-1" WC
- 0-10 VDC output
- +/- 0.5% FSO accuracy
- Price: $ 0.00 (Donated)

http://www.workaci.com/content/adlp-001-w-u-d-0

This sensor was chosen due to its measurement range, output signal, and cost. Based on the preliminary calculations, we found that our max pressure would not exceed 1" water column with a 0.5% full scale output accuracy. This falls within the guidelines given by the work statement. The output signal is 0-10 VDC. Since the sensors were sent as samples, there was no cost associated with obtaining these sensors, which made the ideal for our project.

6.4 Flowrate Sensor

Figure 13: Wika(2017)

Brand: Wika

Sensor: Wika Air Flow Sensor

Specs:

- 0 to 3940 FPM
- 0-10 VDC output
- +/- 5% accuracy for air velocity
- < 0.5 °C for temperature
- Price: $371.31

https://www.kele.com/flow/a2g-20-series.aspx

This sensor was chosen for its ability to measure both air velocity and temperature. By measuring the air velocity and then multiplying it by the cross sectional area of the duct, the flowrate will be calculated in cubic feet per minute. The temperature is used to calculate the density of the air, which can then be used to confirm the pressure readings. This sensor outputs 0-10 VDC with an accuracy of +/- 5% for air velocity and <0.5 °C for the temperature. This meets the criteria in the work statement.

6.5 Power Transducer

Figure 14: Ohio Semitronics (2017)

Brand: Ohio Semitronics

Sensor: GW-010c Power Transducer

Specs:

- 0 – 1000 Watts
- 0 – 10 VDC output
- +/- .2% Accuracy

This power transducer was chosen in order to correctly measure the power consumption of the fan at any time. This transducer is highly reliable and will complete any necessary measurements needed for our system. This transducer is compatible with LabVIEW.

6.6 12 V DC Single Output Power supply

Figure 15: Jameco (2017)

Specs:

- 12 Volt Output
- .5 Amp

We chose this power supply because it supplies 12 volts, which is what the velocity sensor requires, and because it has plenty of amperage to supply the sensor. This requires a separate plug which will convert the AC outlet power to DC.

6.7 24 V DC Single Output Power supply

Figure 16: Jameco (2017)

Specs:

- 24 Volt Output
- .5 Amp

We chose this power supply because it supplies 24 volts DC for our sensors. This requires a separate plug which will convert the AC outlet power to DC.

6.8 Power Cord

Figure 17: Power Cable copyright SpaDepot.com

Specs:

- Provides layer of safety due to built-in GFCI
- AC outlet compatible

This will be used to power the fan.

6.9 NI MyDAQ – Wiring Schematic

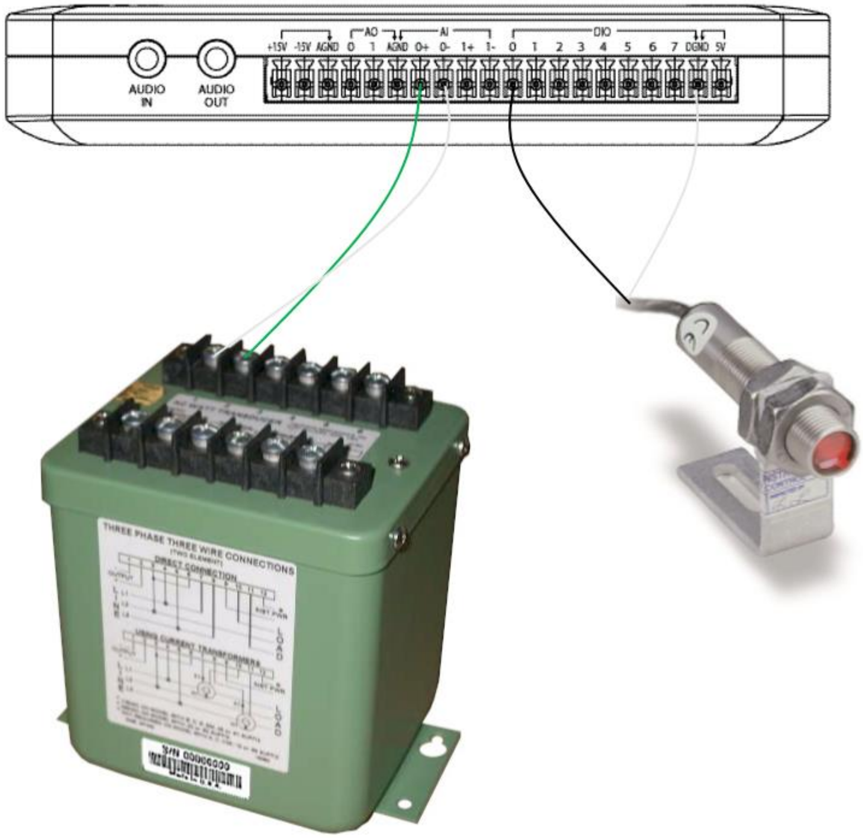


Figure 18: Power transducer and RPM sensor connections

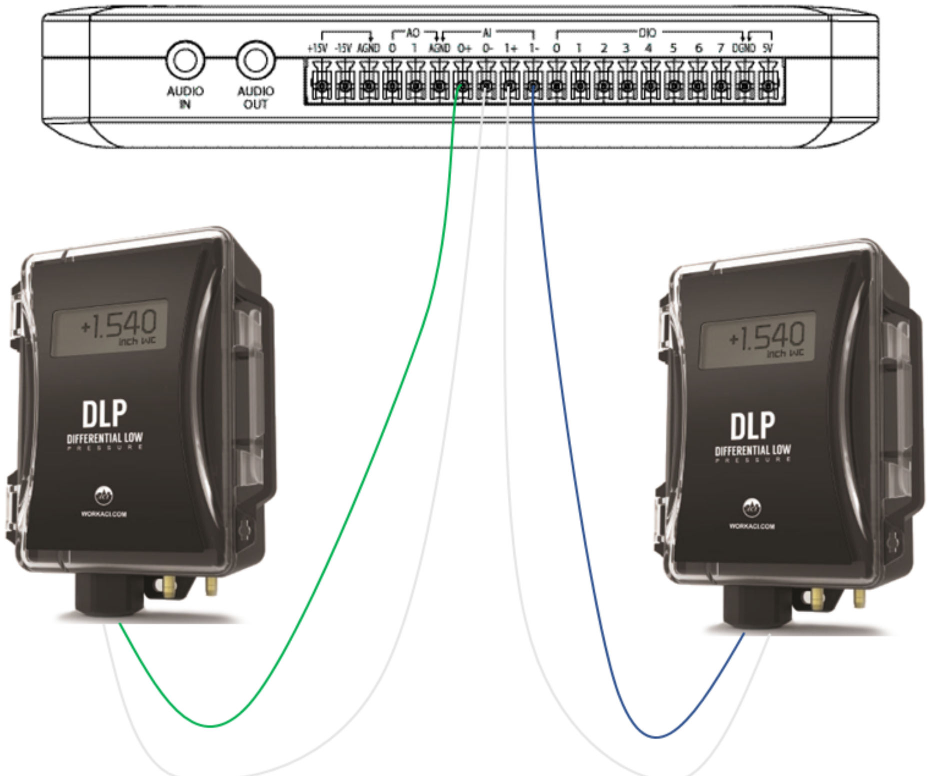


Figure 19: Pressure transducer connections

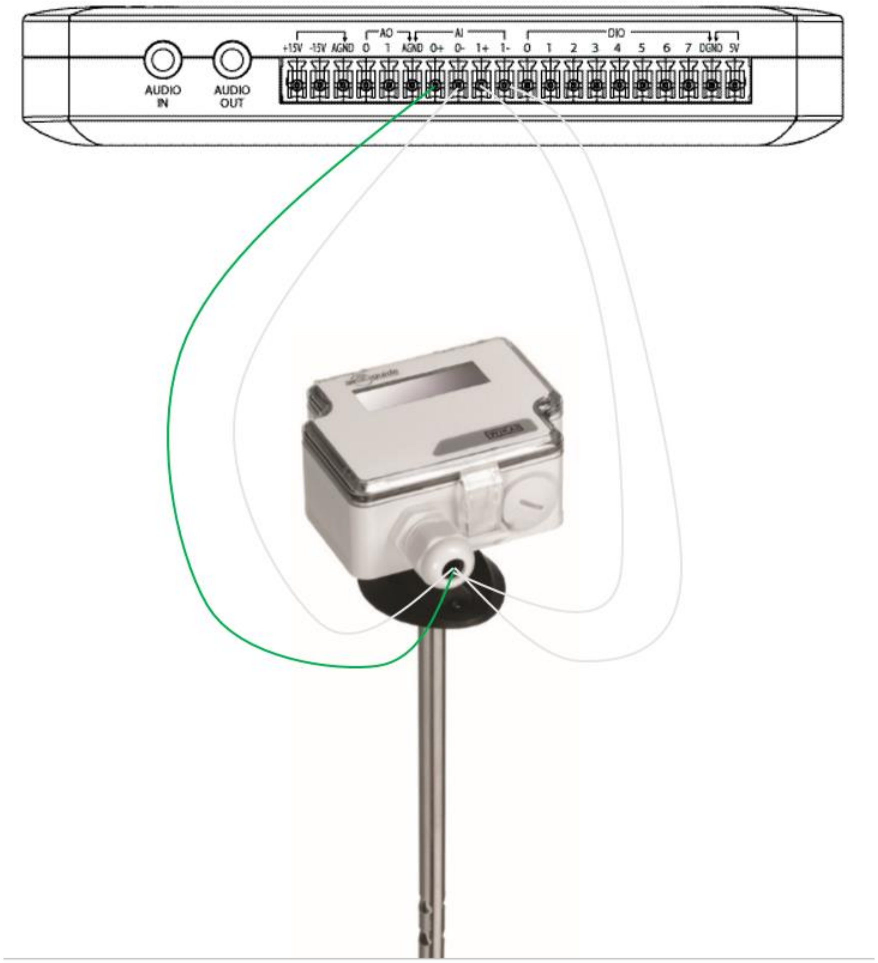


Figure 20: Flowrate and Temperature sensor connection

6.10 User Interface

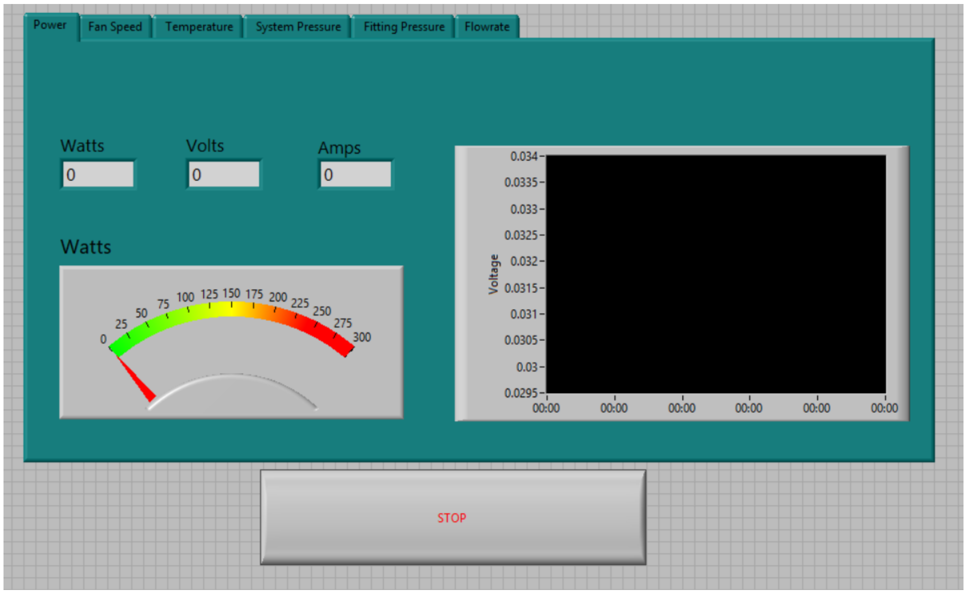


Figure 21: Main user interface (LabVIEW)

The user interface for our laboratory experiments is shown above. This interface allows students to visualize all the necessary input signals from sensors across the setup. Each panel consists of a numeric output, visual output reading, and voltage measurement signal acquired by the DAQ. The interface is considerably the most crucial part of the laboratory set, as it is directly used by the student to gather necessary data.

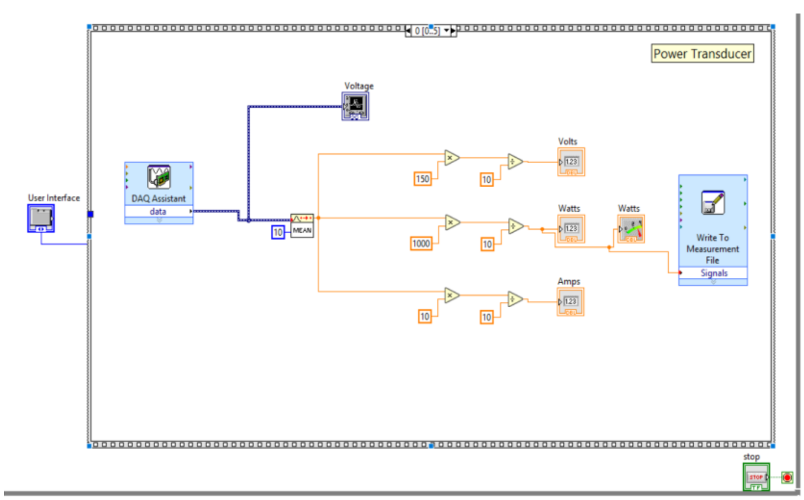


Figure 22: Block Diagram (LabVIEW)

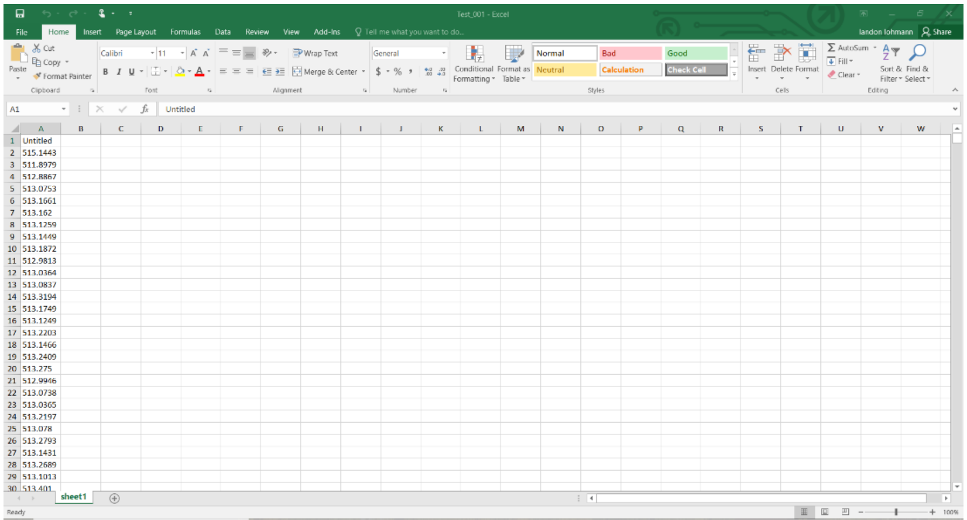


Figure 23: Exported data to Excel

As shown above, the block diagram includes all necessary mathematics as well as voltage configurations to accurately and intelligently gather correct voltage signals from each particular sensor. All sensors output a voltage value from 0-10 volts which is converted to its correct numerical value except for the RPM sensors which has a TTL proportional output. All data is then exported automatically to its individual location in the form of an excel spreadsheet. This will allow students to save all data needed for their lab reports.

7 Marketing Plan

7.1 Summary:

The target markets are engineering programs and technical schools for use in laboratories. The markets will be reached by demonstrating the labs for customers and by reaching out to educators while building long term relationships. The OSU MEEN bachelor program alone has had an average enrollment of over 700 students from 2011-2015. This presents a large market to sell 5-10 units to each university assuming a class size of 10-20 students. The competition sells packages while not providing more parts and procedures to continue improving the overall product experience (gunt.de). The main selling points of our product will be support and flexibility in providing the custom solutions that meet their changing needs. This will be achieved by communicating with ABET to meet their desired standards, listening to customer needs, and offering customization options that align with these requirements. Additionally, the competition doesn't seem to have any products which display clear ventilation so that flow patterns can be seen using flow visualization strings place in duct.

A supplementary market will be custom solutions for HVAC firms to build demonstration setups for their clients. This will provide them an opportunity to show their products in action while educating their customers and building profitable relationships.

7.2 Mission and goals

Provide an intuitive, flexible, hands on laboratory for measurement and demonstration of fan performance and duct flow while reaching largest market

7.3 Available markets

- ABET certified engineering programs
- Over 750 schools are abet certified worldwide (abet.org)
- HVAC trade schools
- Additional educators with an emphasis on hands on technical experience
- HVAC companies
- Demonstrations for potential customers/r&d

7.4 Product Features

- Technical experience
- Hands on laboratory provides students and trainees experience that will bridge the gap between theory and applied knowledge
- Versatility
- Modifiable setup allows to test a variety of systems, tailored to customer needs
- Ease of use
- No specialty training required for operation

7.5 Customer Acquisition

- Build relationships with institutions to meet their needs and provide customer laboratory setups and procedures
- Reach out to accreditation programs to provide system which aligns with their standards and desired outcomes
- Demonstrate product with traveling setup for companies and educators

7.6 Market differentiation

7.6.1 <u>Competitor model:</u>

- Single package sale
- Provide overall setup and diverse set of accessories for flexibility
- No apparent provision to provide custom solutions
- No accommodations for flow visualization

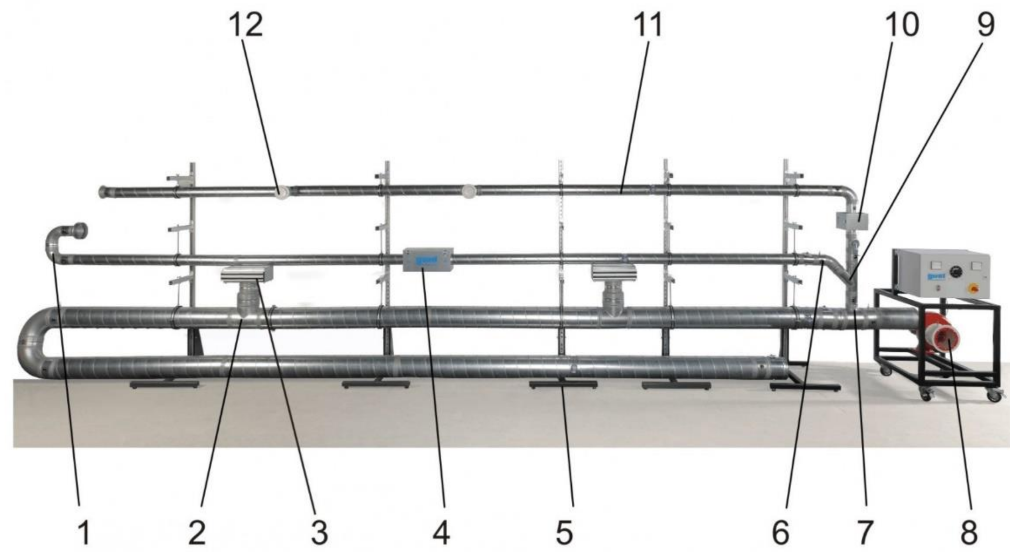


Figure 24: Guntt product: source: http://happevanrijn.com/products/hl-710

7.6.2 Duct 2 model:

- Package sale
- provide initial set up
- Basic package will provide initial lab equipment and range of experiments
- Expanded packages
- Provide additional equipment for expanded labs and complex setups
- Aftermarket
- Custom parts to meet individual program requirements
- Allows user to see flow turbulence through flow visualization strings and clear duct sections

Duct 2 believes that the marketing strategy above will help us corner a large market and carry forward in strong business relationships with our customers while improving the education of students with our product.

8 Commissioning Plan

Commissioning will consist of systematic testing of the system to determine if the system responds as expected to calculated changes.

First ensure that all bolted connections are firmly tightened and no loose connections exist.

First all DAQ and sensors will be inspected to ensure all connections are properly connected.

Ensure the damper is in the full open position

Plug in fan

Set the fan to max speed

Inspect all duct connections and feel for leakage

If leakage is found, adjust duct alignment or replace gasket as necessary

If a connection is found to be loose or not evenly sealing, adjust latch clamps by tightening or loosening the threaded latches.

Inspect the flow visualization strings and ensure they are all glue to the walls of the duct and no tangles are present.

If tangles are present or strings are disconnected, disconnect duct connection and fix strings.

Start LabVIEW and click on the RPM tab

Compare the built in fan speed display on the side of the fan to the displayed fan speed in LabVIEW, if the two values are within +/- 10 RPM, the RPM sensor is properly functioning

Click on the Power tab in LabVIEW to bring up Power interface

At max fan speed, determine the power consumption in watts, expected value is approximately 260 watts assuming a 94% fan efficiency.

If the displayed power consumption is within +/- 10 watts, continue to next step

Further test the power transducer by closing damper ¾ open position. Determine if the power consumption drops sharply, if so, the power transducer is properly function.

Attach precision manometer to tubing for pressure sensor 1, record the pressure drop

Repeat for pressure sensor 2, record pressure drop

Attach pressure sensors to tubing and record 5 second average of the readings.

Compare to precision manometer values.

If pressure values are within +/- .04 in w.c. sensors are fit for use

Place Velocity sensor in duct three foot straight section nearest fittings, if value does not fluctuate more than .35 m/s in a 30 second span, the velocity sensor is fit for use. Note: Ensure that the air inlet hole of velocity sensor is normal to flow direction to ensure accurate reading.

If all the values are in agreement and are within tolerances of expected response and no leakage is seen, then the system will be declared fit for use.

If the system does not respond within tolerances, all instruments and assemblies will be reviewed to determine the issue.

9 Recommendations and Future Work

Duct 2 believes that the product meets all the objectives set in the work statement and syllabus. One way we could have worked more efficiently on this project would have been to perform more research on relevant topics before making design decisions. A lack of knowledge of subject matter was a major limitation on initial development. Looking back on the project now, some design decisions could have been made much more efficiently. An example of how we could have improved our design based on new information is replacing the current static taps with static pressure pitot tubes would further improve the data acquisition for the pressure measurements. Although the current setup with the pressure tap meets syllabus requirements, new pitot tubes would decrease error due to turbulence in the flow. Additionally, more effort in continuously working on documentation throughout the semester could have greatly reduced stress as deadlines such as the PRM, CDR, and final presentation loomed closer. Additionally, the duct might have been sized slightly larger to reduce the total amount of static pressure loss on the damper and allow a more complete fan curve to be produced at higher fan speeds. We could have also reduced our time spent manufacturing by allowing Harrison-Orr to install components like the gasket and latch clamps. Additionally, decisions made on flange dimensions in particular the reducing section could have been re-evaluated to allow a less permanent connection to the fan and damper. The fan curve lab module could be improved by review standards for fan testing and the production of fan curves from ASHRAE standards.

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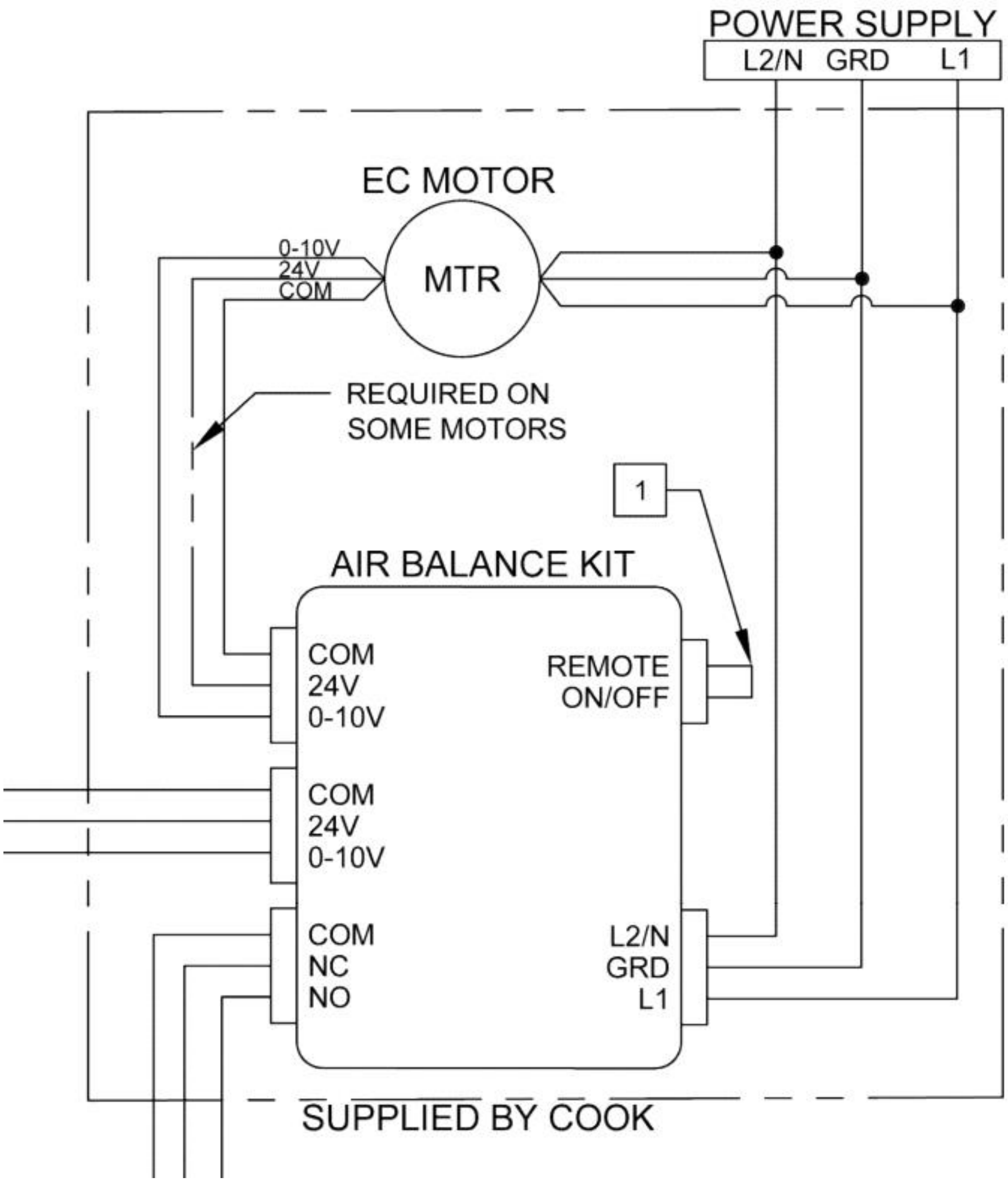
11 Appendix 1: Detailed Budget

ACI DLP Pressure Sensor	Donated	580
Loren Cook CPV-EC 150	Donated	2913.49
Ductwork	Donated	1000
Air Velocity Transmitter + Shipping	Electrical	371.31
Optical LED Sensor	Electrical	150
Sound Meter	Electrical	85
16' GFCI 120V 15a Power Cord	Electrical	63.9
100 Feet 2 Pair Cable 22 AWG Individual Foil Shield UL CL2	Electrical	34.95
GW5-010C Precision AC Watt Transducer	Electrical	371.35
AC/DC WALL MOUNT ADAPATER 12V 5W	Electrical	6.9
AC/DC WALL MOUNT ADAPTER 24V 12W	Electrical	12.3
Scotch Super 88 66-ft Electrical Tape	Electrical	3.98
Gardner Bender 8-Count 6.4mm 4-in Heat Shrink Tubing	Electrical	2.18
Southwire (Common: 1/2-in; Actual: 0.5-in) Metal Flex 25-ft Conduit	Electrical	15
12 in. x 12 in. x 6 in. Junction Box	Electrical	35
UV Black Light Flashlight, AhomePlay Blacklight Ultraviolet LED Pet Urine Detector Bed Bug Finder Dog Stain Remover with 18650 Battery and Charger	Electrical	22.51
Utilitech 2-ft 15-Amp 120-Volt 3-Outlet 14-Gauge Black Outdoor Circuit Breaker And Adapters Extension Cord	Electrical	10.97
Sigma Electric ProConnex 10-Pack 3/8-in BX - MC - Flex Straps	Electrical	1.48
14 GA Single Conductor Wire(20 Ft)	Electrical	5
Hillman 3/8-in x 1.5-in Zinc-Plated Standard (SAE) Serrated Flange Hex Flange Bolt (x80)	Mechanical	70.4
Superstrut 1/2-in Angled Strut Bracket	Mechanical	53.1
Superstrut 1-5/8-in x 1-5/8-in Gold-Galvanized Half Slot Channel Strut (10ft)	Mechanical	176.58
Superstrut 1-in Universal Endcap	Mechanical	40
Waxman 5-in Rubber Swivel Caster	Mechanical	51.88
1/4" Poly Tubing 25 ft length	Mechanical	3.49
Superstrut 3/8-in Straight Strut Nut (5 pack)	Mechanical	57.31
Push to Connect 1/4 inch fitting tees	Mechanical	28.94
Toggle Clamp,150 Holding Capacity (Lb.),1.43 Overall Height (In.),2.21 Overall Length (In.)	Mechanical	48

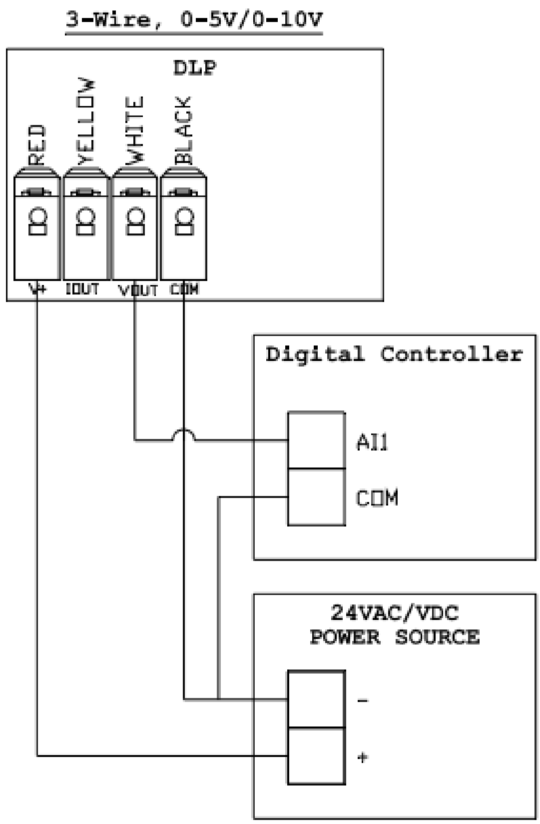
Superstrut 1-5/8-in x 1-5/8-in Gold-Galvanized Half Slot Channel Strut (10ft)	Mechanical	176.58
M-D 10-ft Black Rubber Window Weatherstrip	Mechanical	17.9
10 Ft. DuroDyne MBX Excelon Series Flexible Duct Connector (# 10159)	Mechanical	40
Dwyer Static Pressure Fitting	Mechanical	80
1/2 0.5 inch Flush Mount Black Plastic Body and Sheet Metal Hole Plug Qty 25 by Caplugs	Mechanical	12
Rhumen 3300Yards Glow In The Dark Embroidery Thread (Green)	Mechanical	11
E6000 CLR	Mechanical	21.4
GE Silicone II 10.1-oz Clear Silicone Caulk	Mechanical	23.92
Hillman 2-Count 5/16-in x 5-in Stainless Steel Standard (SAE) Hex Tap Bolts	Mechanical	6.21
Project Pak 25-Count 5/16-in x 3/4-in Zinc Plated Standard (SAE) Flat Washer	Mechanical	2.74
Hillman 5/16-in Zinc-Plated Standard (SAE) Hex Nut	Mechanical	0.66
Stanley-National Hardware 1 Count 5-in W x 2.5-in L x 5/16-in Dia Zinc-plated U-Bolt	Mechanical	10.96
Project Pak 25-Count 3/8-in x 7/8-in Zinc Plated Standard (SAE) Flat Washers	Mechanical	6.48
Superstrut 1/2-in Straight Strut Bracket	Mechanical	7.76
Velcro 90197 Industrial Strength Sticky-Back Hook and Loop Fasteners, 2" x 15 ft. Roll, Black	Mechanical	19.97
Hillman 1/4-in Zinc-Plated Standard (SAE) Nylon Insert Lock Nut	Mechanical	0.96
Hillman 1/4-in x 3/4-in Galvanized/Un-Coated Standard (SAE) Flat Washers	Mechanical	1.92
Hillman 2-Count 1/4-in x 1-in Zinc-Plated Standard (Sae) Serrated Flange Hex Flange Bolt	Mechanical	2.8
Anndason Toggle Latch Clamp 4001 ,100Kg 220Lbs Holding Capacity (6PCS)	Mechanical	62.95
Hillman 100-Count #8-32 x 1/2-in Round-Head Standard (SAE) Machine Screws	Mechanical	5.58
Minwax Red Oak Interior Stain (Actual Net Contents: 32-fl oz)	Mechanical	7.77
Top Choice 3/4-in HPVA Oak Plywood, Application As 4 x 8	Mechanical	49.92
Plytanium 3/8 CAT PS1-09 Pine Plywood Sheathing, Application as 4 x 8	Mechanical	17.48
Hillman 2-Count 3/8-in x 2-in Black Standard (SAE) Hex Flange Bolts	Mechanical	3.78
Rust-Oleum Stops Rust Orange Enamel Spray Paint (Actual Net Contents: 12-oz)	Mechanical	23.28
Rust-Oleum Professional Black Gloss Enamel Interior/Exterior Paint (Actual Net Contents: 32-fl oz)	Mechanical	9.58
Blue Hawk Paint Tray Liner (Common: 11-in x 17-in; Actual: 11.875-in x 17-in)	Mechanical	1
Project Source 9-in Plastic Regular Paint Roller Frame	Mechanical	7.76

12 Appendix 2: Wiring Diagrams

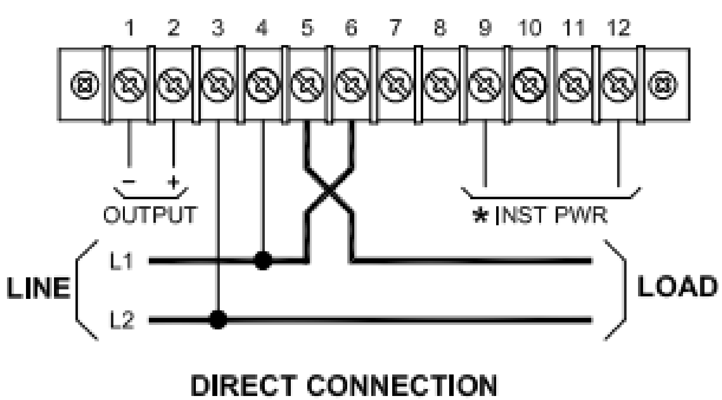
12.1 Fan and fan control



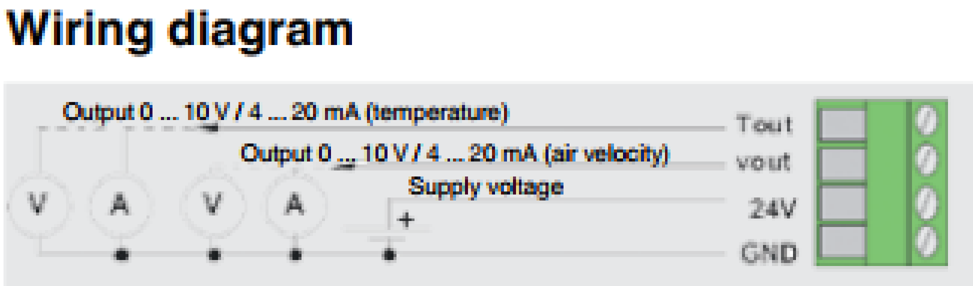
12.2 Pressure transducers



12.3 Power Transducer



12.4 Velocity Sensor



13 Appendix 3: Work Statement

1. **Definitions:**
   Customer – IAC and donors represented by course instructor
   Contractor – Student teams
   System – System for the characterization of fans and duct work fittings

2. **Summary.** Mechanical engineering undergraduate education traditionally included a substantial amount of experimental work. However, a shift of focus towards a more theory based curriculum led to a loss of practical 'gut feeling'-type understanding of the material. The laboratory setup that you will develop as part of your project will support future generations of undergraduate students in obtaining such practical understanding of class material. The final product should be targeted towards a future HVAC systems class at the undergraduate level and include the necessary laboratory documentation for the students to execute experiments.

   The objective of your project is to develop a system for the characterization of fan performance and ductwork fittings (subsequently called '**system**') that includes the following aspects:

   2.1. Measurement of fan curves (pressure vs. volumetric flowrate) at various fan speeds
   2.2. Determination of pressure loss for various different duct components (including elbows and straight sections). You may choose to express the loss coefficients in terms of equivalent straight duct length.
   2.3. Determination of interaction between fittings arranged in series (aka 'system effect') expressed in pressure vs. air velocity relative to baseline

2.4. Integration into an overall learning environment with predefined 50 minute laboratory modules as mentioned above – including the required instructional material.
2.5. An automated controller to emulate constant torque, constant fan speed, and constant flowrate behavior of the fan (teams that include an electrical engineer only).

Within the above aspects you are free to choose the exact implementation. The setup shown on Figures 1 and 2 shows an exemplary system schematic.

3. References.

ASHRAE Fundamentals Handbook: Chapters 1 (Psychrometrics), 3 (Fluid Flow), 7 (Fundamentals of Control), 8 (Sound and Vibration), and 21 (Duct Design)
ASHRAE HVAC System and Equipment Handbook: Chapters 2 (Building Air Distribution), 18 (Fans)
ASHRAE Handbook—HVAC Applications: Chapter 48 (Noise and Vibration Control)
Note: You can access the latest handbook version over the OSU library. For chapter 1 of the fundamental's handbook: The variable μ is undefined – refer to the previous handbook, chapter 1, equations 13 and 14 if required.

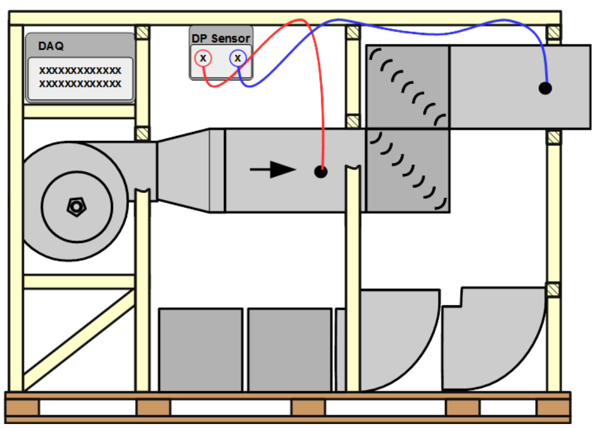


Figure 2: Overall Learning Environment Setup. ***Fan, data acquisition and sensors are mounted on a low cost flexible lumber structure. Ductwork can be built by students in lab experiments using duct pieces stored at bottom of setup. Example configuration shows a vertical offset using rectangular ducts with guide vanes.***

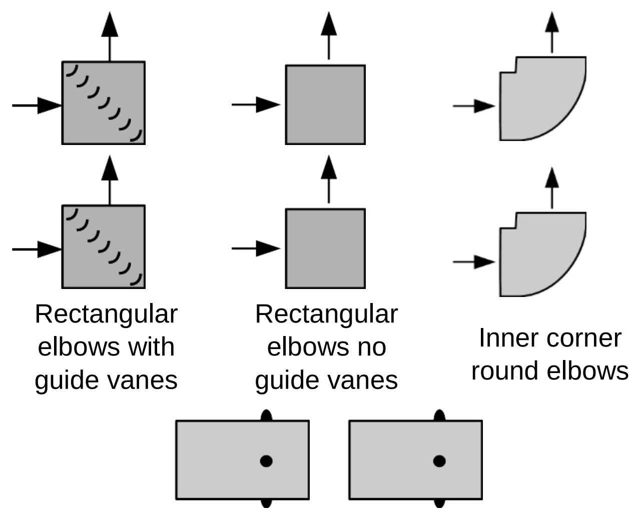


Figure 3: ***Preliminary Duct and Fitting-Kit***

4. Scope.

This document includes all required objectives, Key Performance Parameters (KPP), Key System Attributes (KSA), and Measures of Performance (MOP), for the contractor to provide essential engineering, research, development, test and evaluation.

5. Design Requirements and Constraints

Systems that do not fulfill the subsequently listed requirements and constraints will not be considered for evaluation.

5.1. Available components:

5.1. Available components: The system should be designed around and incorporate the components given in the table below. Substitutions should be discussed with customer. The customer has a limited selection of DAQ systems available as well as laptop computers that may be used without counting against the cash budget available to the group.

Table 1: Specified System Components

Component short name	Details	Budget for total cost calculations
Fan	Variable speed DC fan with motor controller and accessories (customer to provide details)	$2,913.49
Ductwork	May be available through donations (check with customer)	$1,000
Sensors	3 AKS 21M (084N2003) and 2 AKS 21W (084N2031) temperature sensors are available for this project, mfg. Danfoss	$27 + $310

5.2. Cash Budget

A cash budget of $3,500 is available for this group for purchases of additional components, materials, sensors, and supplies. This cash budget will also be used for shipping costs, if applicable. Available components (section 0) do not count against the cash budget but should be reported in the overall project budget.

5.3. Sensor specifications & graphical user interface

Table 2 shows the minimum specifications for the instrumentation as well as additional items to be included in the graphical user interface. Specified uncertainty is shown in square brackets.

Contractor to decide on exact implementation to maximize educational usefulness. Noise level measurements should follow AHRI and AMCA standards within the given financial constraints. Software should allow octave-band level input.

Table 2: Graphical user interface and instrumentation

Item	Range [uncertainty]
Fan Static Pressure	0-2” WC [±0.04]
Fan Flowrate	0-1,400 CFM [±70]

Fan Power	0-100% of max fan power [±5%] of power at minimum fan speed and minimum fan static pressure]
Fan Hydraulic Efficiency	0-100% [±8%]
Fan Speed (measurement)	0-3,600 RPM [±30]
Fan speed (setting)	0[1]-3,600 RPM [50 RPM increments]
Fan curve	As supplied by manufacturer [as provided by manufacturer]
Noise level	30-90 dBA @ 50 Hz to 8 kHz [±2dB]
Test description	Free text entry [NA]

5.4. Speed of operation: The setup should allow testing of 3 different ductwork configurations each at 5 different fan speeds within less than 50 minutes. Acquired data shall include: fan performance data, overall pressure loss, and measurement of the noise at 1 m distance perpendicular to the duct exit as well as at 1 m distance to the fan inlet in axial direction.

All developed learning modules shall be designed for 50 minute class intervals. Pre-class and post-class instructions should include sufficient instructions for the students to complete their experiments and their laboratory report.

5.5. Durability: The test setup must be build strong enough to sustain travel to and from classrooms to a storage location within the customer's facilities. Wheels must be designed to accommodate ½" drops or steps at doorways and/or ¾" expansion joint gaps between building sections. Wheel surface must be rubber or other material compatible with typical classroom flooring and regular tile floor while also capable of running on rough surfaces. A minimum wheel size of 3" is mandatory.

5.6. Cost: The material & equipment cost cap for systems to enter competition is dictated by the cash budget. A maintenance cost plan must be supplied as defined in further detail in the syllabus attachment. Costs do not need to include student time and tooling. A separate cost item (for groups>5 students) is a production type system cost analysis.

5.7. System controls: The system must be equipped with a variable speed fan as well as a throttling device to allow testing of different fan static pressures at various fan speeds.

[1] Minimum allowable fan speed to confirm to fan manufacturer specifications.

5.8. Ease of use: The system can be operated by a typical OSU undergraduate student without special training.

5.9. Documentation: The system is accompanied with a full documentation package outlined in further detail in the syllabus attachments. Learning modules should supply all necessary material to allow students to execute the experiments defined in section 1. Pre-class and post-class instructions should include sufficient instructions for the students to complete their experiments and their laboratory report.

5.10. Aesthetic appeal: The system will be used for undergraduate education. The overall aesthetic appeal is crucial in gaining the necessary excitement for students' successful learning process.

5.11. Power supply: The system should be designed to operate on a regular 15 AMP 115 V NEMA 5-15R power socket using a single NEMA 5-15P plug with appropriately rated cable.

5.12. Size constraints: The develop setup needs to fit within a vertical envelope of 32" (width) by 82.5" (height). This constraint allows the setup to clear through a standard single door as employed in smaller classrooms. The length limit for customer's load elevator if 132" which will need to be reduced based on customer's hallway layout and actual system width. An exact length constraint needs to be develop in collaboration with the customer.

5.13. Safety requirements: The design needs to meet applicable machine safety requirements, including OSHA 1910.212(a)(5), OSHA 1926.300(b), 1910.219(e, if applicable), and OSHA recommended limits for lifting heavy weights.

5.14. Electrical wiring: Electrical wiring above 50 Volts needs to be in accordance with the US National Electrical Code. This includes running all accessible cable in conduit, selection and de-rating of wiring, and proper labelling of electrical boxes with the voltage contained therein.

5.15. Grounding: All metal parts of the setup need to be grounded when installed. Grounding of ductwork through the connection bolts to the main setup is acceptable.